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REDUCING MAIN ENGINE FAILURE USING THE FMEA METHOD IN LPG REFINERIES

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ABSTRACT

The operation of the machine continuously is required to get targets with a high level of effectiveness, so that improper maintenance and handling of the machine can cause a decrease in the level of productivity and efficiency of the engine. With frequent damage to the components of the gas engine needed, the right method is to be able to reduce or inhibit damage that will occur. Failure analysis is done by the cause and effect method, Failure Mode and Effect Analysis (FMEA). The results of the FMEA analysis and risk priority number (RPN) for engine failure with an indication of hot engine temperature indicate the highest RPN 252 in the blocked radiator core, so routine maintenance and checking must be carried out. This shows that engine failure can be minimized by analyzing potential risks to the machine and analyzing the occurrence of component damage from a previous fault history.

KEYWORDS: Engine Failure, Risk, Causal and Effect Method & Failure Mode Effect Analysis (FMEA)

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Original Article

1. INTRODUCTION

Since Indonesia implemented the kerosene to LPG conversion program in 2007, domestic LPG consumption has jumped significantly. This form of commodity is well-known in the community with the brand "ELPIJI" produced by the Pertamina Company. The definition of LPG is in accordance with Government Regulation No. 36/2004, which is "hydrocarbon gas liquefied by pressure to facilitate storage, transportation and handling, which basically consists of propane, butane, or a mixture of both." LPG is a mixture of various hydrocarbon elements derived from natural gas by increasing pressure and decreasing temperature, the gas turns into liquid. LPG components are dominated by propane (C_3H_8) and butane (C_4H_{10}), LPG also contains other light hydrocarbons in small amounts, such as ethane (C_2H_6) and pentane (C_5H_{12}). Under atmospheric conditions, LPG will be in the form of gas, the volume of LPG in liquid form is smaller than in the form of gas for the same weight so that LPG is marketed in liquid form in pressurized metal tubes. To allow thermal expansion of the liquid it contains, the LPG cylinder is not completely filled, only about 80–85% of its capacity, volume ratio between the gas when it evaporates and the gas in a liquid state varies depending on composition, pressure and temperature. According to the specifications, LPG is divided into three types, namely, mixed LPG, propane LPG and butane LPG, and marketed by Pertamina is a mixture of LPG. The specifications of each LPG are listed in the decision of the Director General of Oil and Gas Number: 25K/36/DDJM/1990. LPG can be produced from oil refineries or gas refineries.

Looking at the supply and demand statistics of LPG needs from year to year, where an increase in the amount of production cannot offset the increase in consumption, so that the fulfillment of the shortfall must be met from imports, of course with this import, the government budget burden will be greater and can cause dependence

from outsiders. This makes domestic LPG refineries play an important role in responding to this need, so that the occurrence of disruptions or unplanned stoppages must be avoided because often the production machinery is damaged, ranging from minor to severe damage. In the end, many losses occur: time, product defects, costs and problems increase. So, we need a method damage to that which can analyze and provide treatment policies. As world markets become more profit-oriented, more and more companies and organizations are becoming aware of the importance of maintenance contributions to produce value, while reducing the risk of damage.

The LPG Plant Unit is designed to be able to separate the heavy and light fractions in this case. LPG and condensate from the saturated feed gas stream originating from oil well exploration collected at the collecting station. In general, LPG refineries consist of the following process systems:

- Compression and filtering system: gas compression and filtering process.
- Dehydration system: the process of drying gases from water vapor.
- Cooling system: gas liquefaction process.
- Fractionation system: the process of separating the gas based on boiling point.

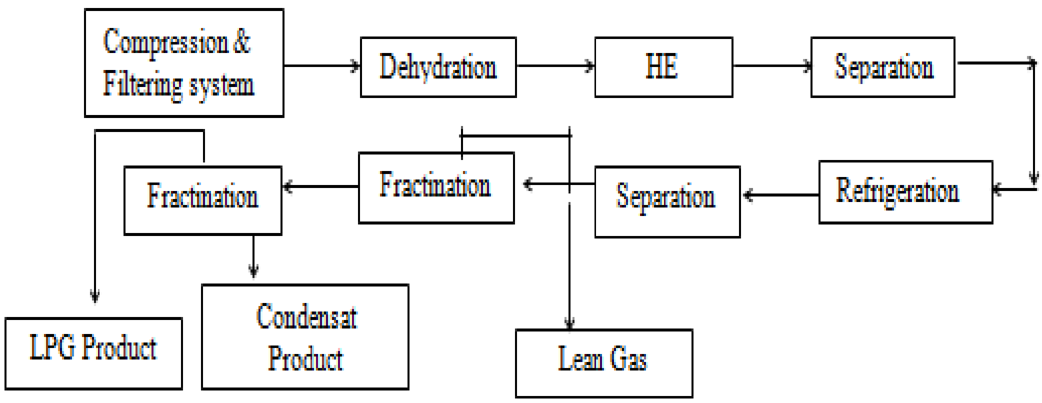

Figure 1: Block Diagram LPG Process.

Of the four processes, the role of each equipment is a success factor in producing LPG with good quantity and quality, so that the efficiency and reliability of LPG refinery equipment must have a clear benchmark, so that equipment damage or unplanned repair activities will not occur which certainly causes losses to the refinery, especially if there is an unplanned shutdown.

Table 1: Damage Data for the 2018 Tambun LPG Refinery

Sl. No.	Main Equipment Unit		Amount of damage	Maintenance Hours	Percentage
1	Compressor	Unit A	4	960	12%
		Unit B	3	96	1%
2	Refrigerant system	Unit A	18	1536	20%
		Unit B	10	1920	25%
		Unit C	**13**	**2160**	**28%**
3	Hot Oil System	Burner	3	72	1%
4	Electricity Supply Unit	Generator set 1	5	528	7%
		Generator set 2	5	96	1%
		Generator set 3	5	360	5%
Total			**66**	**7728**	**100%**

Based on the critical engine damage data table above, corrective damage with the highest number of maintenance hours is on the refrigerant system, especially unit C with a total of 2160 maintenance hours, so that it becomes an object to be examined, because the refrigerant system is one of the main equipment, which has a very important role. It is important to produce quality and quantity of products, where the liquefaction process occurs or the process of converting natural gas from the gas phase to the liquid phase (condensation process) in the LPG production process.

2. LITERATURE REVIEW

The engine is a device that has the ability to convert heat energy possessed by the fuel into motion energy. Based on its function, the engine terminology at Caterpillar is generally used as a main power source (prime mover) on engines, generators, ships or various industrial equipments. Like other machines, a machine will not be able to work optimally if one system on the machine does not work properly because of damage that occurs to one of the components contained in the system. The impact is given when the engine system is damaged, such as engine knocks, low engine power, engine overheating, high exhaust manifold temperatures, etc.

In this work, optimization of maintenance measures to eliminate failures in inspected industrial processes. Implementation of maintenance in industry requires an analysis of behavior systems and their components. According to Assauri (1993), maintenance is defined as the activity of maintaining factory facilities and making the necessary repairs, adjustments or replacements so that there are circumstances of production operations that are according to plan. The condition of the machinery and equipment maintained is an important component in the management of machine/equipment maintenance on the industrial floor. Each machine consists of various types of components, each component has the possibility of experiencing damage and shifting the value of reliability because over time, the reliability value of a machine will decrease and this will indirectly result in productivity or the ability to produce from the machine will also decrease. Some literature publications that are still relevant today are reviewed with the aim of analyzing the problem of machine failure and providing a basis for identifying the root causes of failure to develop corrective action that must be taken, so that in this study, the failure risk analysis used is the Failure Mode Effect and Analysis (FMEA) method. Because according to the Primary Purba Guntur & Humiras Purba (2018); Chen & Wu (2013), Chen, *et al.* (2014); Hu Chen Liu, *et al*., (2015); and McDermott, *et al.* (2009), this method has the ability to represent the level of risk in a process with RPN value indicators. (Roman POPROCKÝ, Jana GALLIKOVÁ, 2017) examines the evaluation of the most disturbing parts of the combustion engine and determines the possibility of errors, which are one of the determinants of Risk Priority Value (RPN). Aghib Ritaldi Siregar *et al.* (2018), Improvements were made based on the recommendation of the largest RPN value of identification and calculation of the RPN for potential failures that caused onset of direct employee overtime costs and costs of using diesel.

2.1 FMEA

FMEA is a systematic method that identifies and prevents products and processes that are problems before they occur. The FMEA focuses on preventing damage, increasing safety and increasing customer satisfaction. This FMEA was developed in the 1960s, which was first developed in the aerospace industry. The main purpose of this FMEA system is to prevent processes and products that are problematic before they occur. FMEA can identify failures, effects and risks in a process or product and then eliminate or reduce failures (McDermott *et al*., 2009). The principles and steps of FMEA focus on the same product/design and process even though they may have different goals. Product/design has the aim to uncover problems with products that will result in safety hazards, multifunctional products and FMEA products can be carried out

at any stage in the design process (initial design, prototype, or final design), or can be used on products that have already been produced, whereas FMEA focuses on process, then a way to uncover the process problems associated with manufacturing products. It will be more helpful if it consists of elements from a process, such as people, materials, equipment, methods and the environment. In this study, FMEA was conducted to see the risks that might occur in maintenance operations and operational activities of the company. In this case, there are three things that help determine the interference, which include:

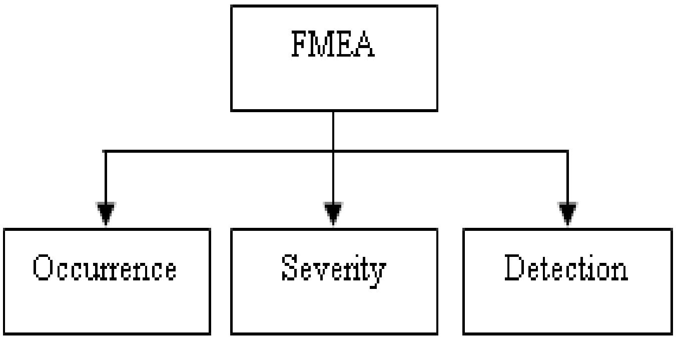

Figure 2: Parameter FMEA.

Occurrence (O)

In determining this occurrence, it can be determined how much interference can cause a failure in maintenance and plant operations.

Severity (S)

In determining the level of damage (severity), it can be determined how serious the damage is, resulting from the failure of the process in terms of maintenance and plant operations.

Detection Rate (D)

In determining the level of detection, it can be determined how the failure can be known before it occurs. The detection rate can also be influenced by the number of controls that govern the process netting. The more controls and procedures that govern the netting system for handling operational maintenance and operational activities of the plant, it is expected that the detection rate of failure can be even higher.

Criteria S, O and D have a score of 1–10, which is used to determine the assessment of each criterion. The RPN value obtained is used to determine the level of risk and determine the priority of improvement. Higher value of RPN indicates a high level of risk and a high priority for prevention and improvement of actions (McDermott, *et al*., 2009). Calculation of the RPN value can be seen in the equation below:

$$RPN = S \times O \times D$$

2.2 Identification

From the data table 1.1, research will be carried out on unit c refrigerant systems. This system in the LPG processing industry has special handling in its operation, so that if the operating system or maintenance in the industry is not good, then the possibility of engine damage will often occur. Finally, the company's productivity in pursuing the quality and quantity of LPG decreases drastically, so it can be concluded that the low reliability of the initial gas engine driver will

make the reliability of the entire refrigerant system decrease, so that the companies productivity will also decrease, as the reliability of the engine unit decreases. From this condition, a thorough evaluation of the engine operating system needs to be carried out in terms of engine capacity design, operation and maintenance carried out by the operator independently as well as periodic maintenance carried out by the maintenance team, so that it is expected that increasing the reliability of the machine (system) will certainly reduce the increase in costs and maintenance and productivity of the company to be improved.

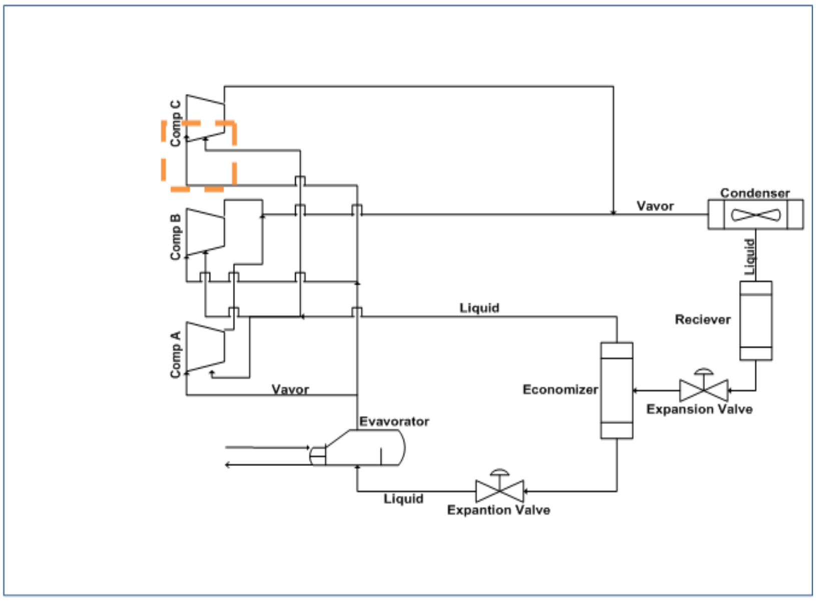

Figure 3: Flow Diagram Refrigerant System.

Equipment Function

- **Compressor:** to increase the pressure of the refrigerant vapor that comes out of the evaporator and simultaneously flows into the condenser.
- **Condenser:** to condense the refrigerant vapor out of the compressor as a medium for cooling water or air.
- **Expansion tool:** to reduce the pressure of liquid refrigerant coming out of the condensate and drain it to the evaporator.
- **Evaporator:** to vaporize liquid refrigerant coming out of the expansion device. A large amount of heat is needed to remove the refrigerant. The heat is taken from other fluids that flow in the tube and is passed in the evaporator, so that the temperature of the fluid drops.

To facilitate research, the limitation will be focused on the screw compressor drive engine of the Caterpillar brand (tag number: Cat G3512). The Tambun LPG plant uses the G-3512 gas engine, which functions as the initial drive of the compressor screw in the refrigerant system (tag number; Austcold C) to condense/liquefy natural gas from the gas phase to the liquid phase, so that it is easily separated in the LPG purification process.

A Caterpillar gas engine is a caterpillar product, which is a spark that uses gas fuel, where a mixture of air and gas is compressed and ignited with a spark plug. In the operation of the Caterpillar 3512 gas engine, there are several main systems, namely, the fuel system, the cooling system, the lubricating system and the electrical system.

Figure 4: Gas Engine Catterpillar G3512.

Specification Gas Engine Catterpilar G3512

Bore	170 mm (6.7 in.)
Stroke	190 mm (7.5 in.) Displacement.
	51.8 L (3158 cu. in.)
Aspiration	Turbocharged-Aftercooled
Digital Engine Management	
Governor and Protection	Electronic (ADEM™ A3)
Combustion	Low Emission (Lean Burn)
Engine Weight, net dry (approx) 6677 kg (14,720 lb)	
Power Density	8.9 kg/kW (14.7 lb/bhp)
Power per Displacement	19.3 bhp/L
Total Cooling System Capacity	162.8 L (43 gal)
Jacket Water	147.6 L (39 gal)
Aftercooler Circuit	15.1 L (4 gal)
Lube Oil System (refill)	336.9 L (89 gal)
Oil Change Interval	1000 hours
Rotation (from flywheel end)	Counterclockwise
Flywheel and Flywheel Housing	SAE No. 00
Flywheel Teeth	183

Cooling system on the engine is a system that serves to keep the engine temperature in ideal conditions. The engine is not an instrument with perfect efficiency, not all of the heat from combustion is converted to energy, some is wasted through the drain and some is absorbed by the material around the combustion chamber. High-efficiency engines have the ability to convert heat from combustion to energy that is converted into mechanical with only a small amount of heat wasted. Engines are always developed to achieve higher efficiency, but also consider economic, durability, safety and environment friendly factors of the five engine systems, cooling system is the biggest factor that can affect engine life.

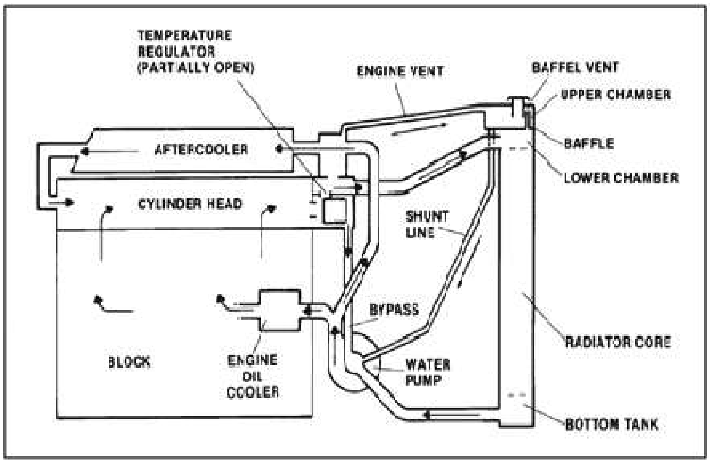

Figure 5: Cooling System.

3. METHODOLOGY

To find out the causes of engine failure, an analysis of the causes of the six big loss factors is carried out using a causal diagram. The analysis is carried out only on the dominant six big loss factors, i.e., the breakdown loss is intended so that the analysis is carried out more efficiently and focused on the factors that have the most influence that causes low productivity of the gas engine. The FMEA method is used to determine the critical level of damage identified, so that it can be known, which factors are causing the failure mode of the main damage to the equipment. The data is taken from daily report data and operational standards that are currently used for improvement.

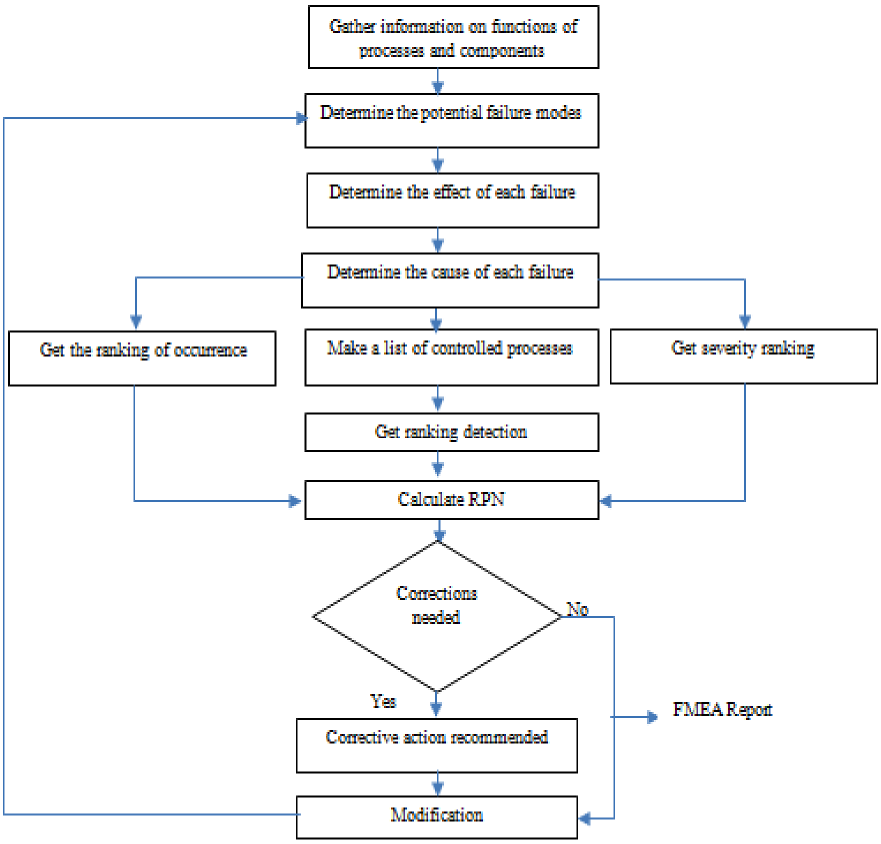

Figure 6: Flowchart of FMEA.

Table 2: Suggested Guideline for Selecting Level of Severity

Effect	Criteria: Severity of Effect	Ranking
Hazardous without warning	Effects safe operation without warning	10
Hazardous with warning	Effects safe operation with warning	9
Very high	Major Disruption, item has to be scrapped, customer discomfort	8
High	Loss of Primary function, Customer dissatisfied	7
Moderate	Minor Disruption, item has to be scrapped, customer discomfort	6
Low	Minor Disruption, item can be reworked, reduced performance	5
Very Low	Minor Disruption, item can be reworked, Customer dissatisfied	4
Minor	Minor Disruption, defect noticed	3
Very Minor	Minor Disruption, noticed by average customer	2
None	No effect	1

4. RESULTS AND DISCUSSIONS

4.1 Availability Analysis

- Operational Availability (Ao) calculation in January 2018 with the following conditions:
- The system operates 24 hours, stated as available time.
- Downtime is the time of damage or total repair hours.
- Number of failures is the frequency of damage to spare parts for a month. Then

Available time = 24 hours/day x 31 days = 744 hours

Downtime = 27.16 hours

Number of failures = 1

MTBF = (744 – 27.16) hour/1

= 716 hours

MTTR = 27.6 hours/1

= 27.6 hours

Ao = 716 hours/(716 + 27.6) hours

= 0.96290323 = 96%

Table 3: The Calculation Result Availability Rate and MTBF MTTR

Sl. No	Period	Loading Time (Jam)	Downtime (Jam)	Operating Time (Jam)	Number of Failures	MTBF	MTTR	AR (%)
1	January	744	27.6	716	1	716	27.6	96%
2	February	672	240	432	2	216	120	64%
3	March	744	120	624	6	104	20	84%
4	April	708	210.5	490	5	98	42	70%

Table 3: Contd.,

5	May	741	93.45	631	7	90	13	87%
6	June	48	8	40	1	40	8	83%
7	July	729	16	710	3	237	5	98%
8	Augustus	744	20.6	723	7	103	3	97%
9	September	720	618.53	101	5	20	124	14%
10	October	744	380.58	363	5	73	76	49%
11	November	715	75.25	640	5	128	15	89%
12	December	744	264	480	2	240	132	65%

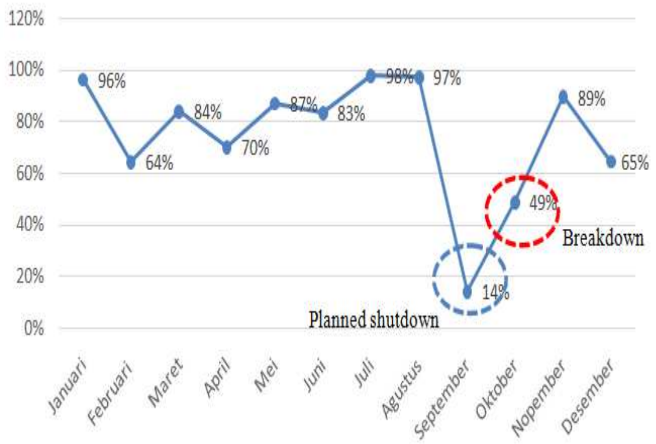

Figure 7: Availability of Gas Engine Unit C in 2018.

From the graph above, it is found that the highest availability value occurred in July as much as 98% with 16-hour downtime, while in September, a planned shutdown was carried out, namely, top overhaul work for 21 days or 3 weeks, while in October, the lowest value was obtained with a value of 49% with downtime of 380.58 hours. From the results of the calculation of losses that have been done, the authors use the Pareto diagram to find out the percentage of failure that occurs when the C engine is running and gets priority on which type of damage should be solved.

4.2 Pareto Diagram Analysis

Based on operational data in 2018, there were 14 times of damage within 90 days, with the highest amount of downtime of 456 hours/18 days on damage to high engine temperature, as shown below:

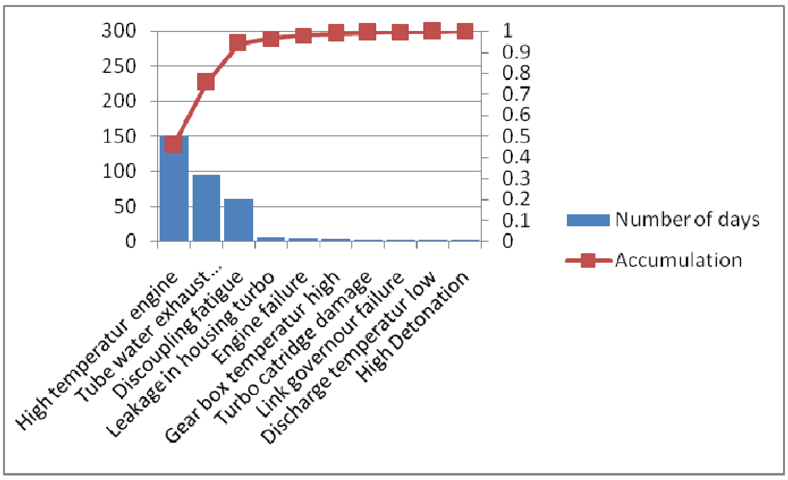

Figure 8: Pareto Diagram.

Based on figure 8, we can know that the biggest damage caused by

- High Temperature Engine
- Tube water exhaust manifold leak
- Disc coupling fatigue
- Leakage in housing turbo

After knowing which damage often occurs and then to find out the root cause, which is analyzed using a fishbone diagram. The factors analyzed in the fishbone diagram are human or manpower, machines, methods, materials and work environment.

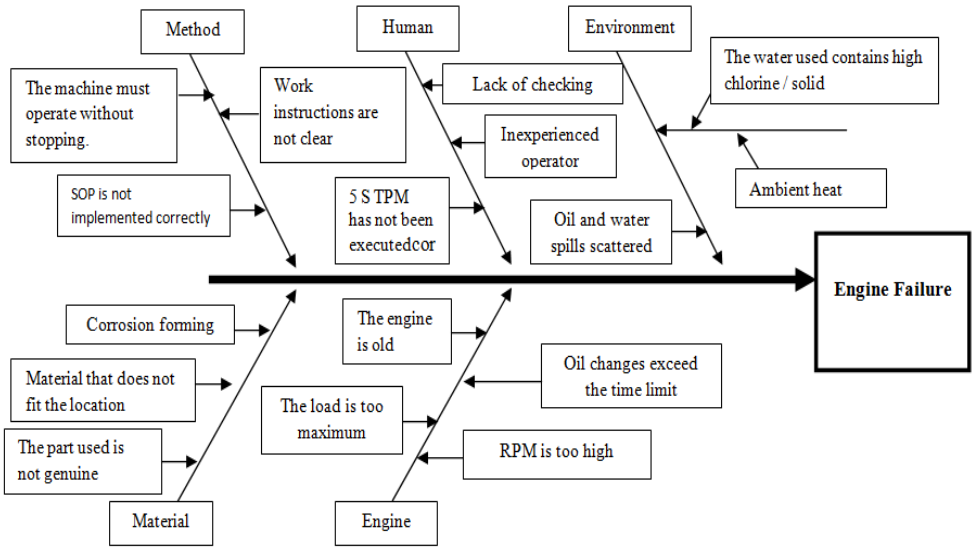

Figure 9: Diagram Ishikawa.

Based on the analysis of cause and effect diagrams, things which cause the engine gas and engine failure are as follows:

Table 4: Root Cause effect Analysis

Damage Factor	Cause
Humans/Operators	(a) Less thorough when maintaining, cleaning and inspecting the machine so that the components of the machine being worked on are not observed.
	(b) The operator is less responsive when watching the engine so that small damage that has the potential to cause large damage is often overlooked.
	(c) Lack of knowledge and experience of the operator regarding the condition of the engine components, which causes the operator to do less precise handling in inspecting engine components.
	(d) 5S has not run well.
Machinery/equipment	(a) Damage to one part/component of the machine so that it can hamper the smooth production.
	(b) Old engine age. This is made worse because the machine works 24 hours, which results in faster component life.
	(c) Loads that are too forced to pursue production reach the maximum point.
Work method	(a) Operators do not carry out maintenance of the machines according to the Standard Operation Procedure (SOP) so that the machines often experience problems when operating.

	(b) The maintenance process is not standard so the inspection and maintenance schedule is not routine. Free time to carry out preventive maintenance is not routinely available because sometimes machines have to operate non-stop.
Material/Spare part	(a) The material used is not suitable for tropical environments.
	(b) The material used is not a genuine part.
	(c) Materials needed are indented due to the absence of stock in the warehouse.
Environment	(a) Environmental conditions that always put the operator and maintenance in a high temperature and high noise level and dusty, resulting in an error in the production process and a long time in carrying out repairs.
	(b) The water used for the cooling process contains chlorine, which is high enough so that the engine matrial is easily corrosive. There is also mud and moss that can make the radiator tubing incompressible.

4.3 FMEA Analysis (Failure Mode and Effect Analysis)

By identifying the causes of machine failures using FMEA, we will know the potential causes of failure and also know the effects or impacts caused by failure. At this stage, we analyze components that are critical and often damaged so that if there is damage to the component, then how far it will affect the overall system function. Thus, we will be able to provide more treatment to these components with appropriate maintenance measures.

Table 5: FMEA Analysis of High Temperature Engines

Description Failure	Cause	S	O	Proposed Maintenance	D	RPN
Low coolant level	a.1. Leakage on the radiator or engine coolant line	8	5	Operator checks every 2 hours	6	240
Low Air Flow Past Radiator	a.2. Clogged radiator cores	6	6	Cleaning radiators every PM 1000 hours	7	252
	b.2.Cooling fan rotation not fulfilled	5	3	Cleaning every PM 1000 hours	7	105
	c.2.Sagging or worn fan belts and pulleys	5	5	Visual check and greasing	6	150
Insufficient Cooling System Pressure	a.3.Circulation pump is not functioning properly	1	7	Operator checks every 2 hours	7	49
	b.3.Broken radiator cover	3	3	Operator checks every 2 hours	3	27
	c.3 Clamp the sagging connecting hose	3	3	Operator checks every 2 hours	3	27
Coolant Flow Less	a.4. The radiator is blocked on the inside.	7	5	Cleaning radiators every PM 1000 hours	7	245
	b.4.The function of the water pump is not optimal	2	2	Cleaning every PM 1000 hours	2	8
	c.4. The thermostat is stuck	2	2	Operator checks every 2 hours	2	8
Inlet temperature is high or blocked	a.5.Ambient temperature is high.	3	5	Operator checks every 2 hours	8	120
	b.5. Screen clogged on engine room fan blower	5	2	Operator checks every 2 hours	7	70
	c.5. Dirty core after cooler	5	7	PM per 1000 hour	5	175
	d.5.Turbocharger damaged or coated in carbon.	7	5	PM per 1000 hour	5	175
Low Heat Transfer due to a blockage in the radiator	a.6.Insufficient water flow through heat exchangers	2	7	Check the water content every month	5	70
	b.6.Scale on tubing and liner wall or cylinder head.	3	5	PM per 1000 hour	5	75
The exhaust is	a.7.Clogged exhaust/muffler	3	5	PM per 1000 hour	5	75

	b.7. Turbocharger broken	7	5	PM per 1000 hour	7	245
	c.7.Failed function on waste gate	7	3	PM per 1000 hour	5	105
Ignition timing does not match the fuel burn point	a.8. ECM sensor has a problem	3	3	Operator checks every 2 hours	3	27
Mixture of air and fuel does not balance	a.9. Problematic air filter	2	2	Operator checks every 2 hours	2	8
	b.9. Governor has a problem	3	3	Operator checks every 2 hours	3	27

Based on the FMEA calculation in table 4.3 above, the RPN value varies with the smallest value of 8 and the largest value is 252, which is the radiator core which is clogged, so it can be concluded that engine failure with an indication of high engine temperature is caused by several factors, as mentioned above, so that prevention is optimally done so that the incident does not recur.

5. CONCLUSIONS

This research was conducted in the LPG gas processing industry with the mission of increasing the reliability of the main engine to reduce engine failures causing the production of stopped LPG, namely, by increasing the reliability of the main engine, especially in gas engine system components by finding solutions to eliminate the greatest or most dominant potential as a cause of damage and to plan appropriate maintenance measures so that production can be maintained. As for suggestions to reduce the effects and the potential for high engine temperatures to conduct regular radiator cleaning, check water regularly to minimize the risk of high chlorine or other solids such as mud, routine inspection by the operator on each parameter and make sure the engine is clean, there are no spills, oil, dust, or anything that can block the rotation of the wind on the radiator and reduce radiator performance.

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